POSSIBILITIES FOR IMPROVING ROCK FRAGMENTATION IN LIMESTONE QUARRIES

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ABSTRACT

The blasting parameters for a 6-month period of observation is studied for a limestone quarry. From the data available the possibilities for improving the rock fragmentation are studied. Three comparison analyses were conducted in order to determine the suitability of using mid-bench boosters and their potential effect for improving the rock fragmentation size. In addition, two blasting patterns were compared for 110 mm blastholes, as well two blast hole diameter performances were compared: 89 mm and 110 mm.

INTRODUCTION

Problems regarding the blasting parameters in quarry blasting may be trivial in mining, however, the approach for solving them remain individual for each mining site. In addition, subtle tweaking of the blasting parameters tends to seek a solution which satisfy conflicting conditions, which further makes the topic of optimizing blasting activities relevant (P. Shishkov, 2019). In quarrying blasting needs to satisfy several conditions depending on type of quarry (the excavated mineral, annual output), the location of the quarry, the quality conditions regarding the quarry’s end product, etc. For some special conditions in dimension block blasting, special requirements of blasting activities are required to be followed (P. Shishkov, N. Stoycheva, 2019). However, in limestone quarrying the main condition which has to be met is the rock fragmentation size. As in any blasting activity this has to be achieved while maintaining the safety of the field work as well as the negative blasting effects.

CASE STUDY

In this case study blasting activities in a limestone quarry, situated in central Bulgaria, were observed in order to identify certain possibilities for improving rock fragmentation. The main application of the limestone from the quarry is for road foundation. During a period of 6 months the blasting results, in term of rock fragmentation size and blasting parameters, have been tracked in order to establish a near-optimal solution for the blasting parameters. The quarry utilizes blasting activities once per week and for the observed period a total of 26 blast were observed. The parameters which have been observed and improved over the period of 6 months are the following ones:

- Booster presence (yes or on);
- Blast hole diameter (89 mm or 110 mm);
- Blast hole depth (in terms of subdrilling length);
- Powder factor (in terms of burden and spacing);
- Drilled blasthole meters per cubic meter material.

USED METHODOLOGY FOR CALUCLATING BLASTING PARAMETERS

No buildings or facilities are located near the quarry, which is an argument that in a radius of 450 m no fly rock accidents or seismic issues could occur from regular blasting. Therefore, all blasting parameters are calculated regarding the 450-meter radius of the danger zone.

Powder factor

As in any rock blasting problem, the first parameter which needs to be determined is the powder factor. Different authors point out that for the proper fragmentation of softer limestone ($f < 8$) a powder factor of 0,25 – 0,4 kg/m³ (B. V. Gokhale, 2011) or 0,4 – 0,5 kg/m³ (I. Koprev, et al., 2017), (P. Shishkov, 2019) is suitble. Harder limestone $f \geq 8$ requires a bigger quantity of explosive, which leads to the estimated powder factor to be 0,4 – 0,6 kg/m³ (B. V. Gokhale, 2011) or 0,45 – 0,7 kg/m³ (I. Koprev, et al. 2017), (P. Shishkov, 2019).

Based on B. Rzhevski's methodology the powder factor can be theoretically established, based on the rock strength of the blasted rock. For obtaining a blasted rock with a maximum fragmentation size of 500 mm, the following formula is proposed (H. Stoev, 2013):

$q = 0{,}73 \, . \, 10^{-2} f + 0{,}349$ kg/ m³ (1)

where

q – powder factor, kg/m³;

f – Protodyakonov's rock strength index.

In limestone blasting for the purpose of obtaining material for road foundation, the rock strength index is f = 8. Therefore, the theoretical powder factor determined by formula 1 is q = 0,345 kg/m³.

Blasthole parameters

The formula used for calculating the crest burden (W) is as follows (P. Shishkov, 2019):

$$W = 53.K_T.d\sqrt{\frac{\Delta.e}{\rho}}\left(1{,}6 - 0{,}5.m\right) \quad , \text{m} \qquad (2)$$

Where

K_T – rock discontinuity factor (assumed 1,1);

d – blasthole diameter, m;

Δ - Explosive density, kg/dm³;

e – Blasting agent strength factor (assumed 1);

ρ – rock density, t/m³.

The subdrilling length (L_{sd}) for rock types with a medium strength index is determined by the following formula (P. Shishkov, 2019):

$L_{sd} = (7 – 10) \, . \, d$, m (3)

$L_{sd} = (0{,}1 – 0{,}3) \, . \, W$ (4)

Where

d - blasthole diameter, mm;

The stemming length (L_{st}) for better rock fragmentation is calculated in the following manner (P. Shishkov, 2019):

$L_{st} = (20 – 25) \, . \, d$, m (5)

$L_{sd} = (0{,}7 – 1) \, . \, W$, m (6)

The blasthole parameters for the two radiuses are represented in table 1.

Table 1

Number	Parameter	Symbol	Unit	d=89 mm	d=110 mm
1	Protodyakonov strength index	f		8	8
2	Bench height	H	m	10,0	10,0
5	Average blasting volume	V_{bl}	m³	7500,0	7500,0
6	Rock density	ρ	t/m³	2,8	2,8
7	Mass of explosive per meter of blast hole column	p	kg/m	5,0 – 5,5	8,55
8	Crest burden	W	m	3,4	4,36
9	Spacing	a	m	2,5	3 or 4,5
10	Burden (drilling pattern)	b	m	2,5	3 or 4,5
11	Subdriliing length	L_{sd}	m	0,9	1,1
12	Blasthole length	L_{bh}	m	10,9	11,1
13	Stemming length	L_{st}	m	3,0	2,2
14	Explosive length	L_{ex}	m	7,9	8,9
15	Ammount of explosive per blasthole	$Q_{bh.}$	kg	43,65 – 45,89	74,37 - 77,8
19	Blasthole drilling length per cubic meter	l	m/m³	0,1161 – 0,1184	0,0488 - 0,0710
20	Powder factor	q	kg/m³	0,466 – 0,490	0,335 – 0,487

Type of explosive

Two types of explosive are generally used in the quarry – ANFO and Emulsion explosive. However, for this case study the blasting operations only with ANFO have been taken into account, as it is the more frequently used explosive due to its low selling price. In addition, during the 6-month period blasting operations with an Emulsion explosives are very few. Therefore, such a comparison between blasting results from the two types of explosives are inconclusive due to the amount of data available, which is not enough to make a thorough comparison analysis. For this reason, the type of explosive for all blasting operations can be assumed as a constant with the use of ANFO. In addition, all the considered cases use a primer, placed in the bottom of the drillhole, while several cases have used a booster, placed on the mid-bench level.

Firing pattern

The firing pattern for this case study is the echelon firing pattern for two main reasons – 1) its relative simplicity, compared to other firing patterns and 2) the mining technology of the quarry, which requires bench blasting activities in order for the quarry to expand. The delay between blastholes within the same row is 17ms, while the delays, used between different rows is 25 ms. Compared to other firing patterns in small mining sites and quarries, these delays are not distinctly different and can be considered as conventional for the needs of quarry blasting.

RESULTS

The results from the observations for a six-month period show the following dependencies in regards of the following groups:

Initiation method

In terms of applying variations in the explosive initiation method – best fragmentation results were obtained when using 1 booster placed at the mid-bench level in addition to the primer is placed in the bottom of the drill hole. This can be explained due to better blasting energy distribution inside the blasthole, which provides a better possibility for obtaining a full detonation process of the explosive inside the blast holes. This further leads to the higher velocity of detonation, as well as the improved distribution of the explosive energy within the rock mass (from a geometric point of view). The obtained results confirm what previous authors have also established, that boosters placed at regular intervals may improve fragmentation (B. V. Gokhale, 2011). The results were obtained for a drilling pattern of 4,5 x 4,5 for a blasthole diameter of 110 mm as shown in table 2.

Table 2

Mid-bench booster (yes or no)	**Yes**	**No**
Number of blasting activities	9	9
Average powder factor, kg/m³	0.329	0.341
Rock fragmentation size (100% of the material), mm	1 - 600	1 - 700

However, the relatively small difference between the two powder factors is inconclusive from a statistical point of view to draw a certain conclusion whether a smaller powder factor in general can achieve a better fragmentation result. Furthermore, more observations are necessary in order to gain a better certainty for the achieved difference in the rock fragmentation size and owe its nature to the presence of a mid-bench booster and not to other unknown present factors.

Choice of diameter results

From the observed blast hole diameters, the diameter of 89 mm achieves better results in terms of rock fragmentation (0 – 100 mm). This can be reinforced by smaller burden and spacing distances for the diameter of 89 mm, compared to the diameter of 110 mm. The smaller burden and spacing distances directly correspond to a “denser” blasthole pattern which to the improved blasting energy distribution within the rock mass. This further reinforces previous studies on similar topics that blast hole diameters smaller than 150 mm prove to be more optimal for rock fragmentation, rather than diameters above 250 mm (V. Mitkov, 2020). However, using a smaller diameter for blastholes leads to the greater amount of drilling works which needs to be done in order to achieve a similar result in terms of rock fragmentation (table 3).

Table 3

Blasthole diameter	**d = 110 mm**	**d = 89 mm**
Burden x Spacing	**3 x 3**	**2,5 x 2,5**
Number of blasting activities	4	4
Average powder factor, kg/m³	0.487	0.478
Average total blastholes drilling length, m	532.8	871.2
Average drilled blasthole meters per cubic meter material, m/m³	0.0710	0.1162

In the case of a diameter of 89 mm the fragmentation may be less, but it comes to the higher powder factor, as well as the increased total blasthole drilling length in comparison to the diameter of 110 mm. Whether the improved fragmentation has to be further investigated when including crushing costs in either case in order to evaluate the full economic potential of either cases.

Suitable drilling pattern

Table 4 represents the blasting results for 2 cases of drilling patterns: 3 x 3 and 4,5 x 4,5. Each of the results are achieved for a blasthole diameter of 110 mm.

Table 4

Burden x Spacing	**3 x 3**	**4,5 x 4,5**
Number of observations	4	18
Average powder factor, kg/m³	0.487	0.335
Average total blastholes drilling length, m	532.8	366.3
Average drilled blasthole meters per cubic meter material, m/m³	0.0710	0.0488
Rock fragmentation size (100% of the material), mm	0 - 120	0 - 700

The obtained fragmentation size results from a drill hole pattern 3,0 x 3,0 m are with a maximum fragment size of 0 – 120 mm, while the fragmentation size results with a pattern 4,5 x 4,5 m are in the interval 0 – 600 mm. This can be further used when the blasted material needs to have a smaller fragmentation size for different purposes of the final product of the quarry. Nevertheless, the quarry uses a mobile crusher for obtaining fragmentation sizes + 50 mm and screening to sizes of 0 – 5 mm, 5 – 25 mm.

CONCLUSION

The 6-month observation period was beneficial for identifying the main tendencies of the influence of key blasting parameters on the rock fragmentation size.

- The use of a booster in the mid-bench level can be helpful for achieving the same or better fragmentation results. However, more observations are required in order to gain a better certainty and owe the different results to the presence of a mid-bench booster and not to other random factors.
- The diameter of 89 mm may be better in terms of fragmentation size, but it has to be further investigated whether if it is economically optimal when costs for crushing operations are included in the total costs equation.

- The drilling pattern of 4,5 x 4,5 m could be used in further blasting activities, as it ensures a suitable rock fragmentation where the rock size is smaller than the width of the mobile crusher's feed width. However, the feasibility of the 3 x 3 m drilling pattern has to revisited when including the costs for crushing operations.

The observation of the blasting results as an on-going process will continue to be conducted in order to identify other possibilities for achieving better fragmentation with less powder factor and drilling works. In addition, including future results for the mobile crusher performance in terms of rock fragmentation of the material feed can provide sufficient information for the optimal drilling and blasting configuration when looking into relevant costs for achieving a certain fragmentation for the end product of the limestone quarry.

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